

# Is There a String Theory Landscape: Some Cautionary Remarks

Michael Dine

*Santa Cruz Institute for Particle Physics, Santa Cruz CA 95064*

## Abstract

There is evidence that string theory possesses a large discretuum of stable and/or metastable ground states, with zero or four supersymmetries in four dimensions. I discuss critically the nature of this evidence. Assuming this “landscape” exists, anthropic explanations of some quantities are almost inevitable. I explain that this landscape is likely to lead to a prediction of low energy supersymmetry. But we argue that many features of low energy physics are not anthropic and, as currently understood, the landscape picture will get them wrong. This indicates that this viewpoint is potentially falsifiable. Moreover, if it is correct, many questions must be answered through more conventional scientific explanations. This is based on talks presented at the conference QTS3 at the University of Cincinnati and at the KITP conference on Superstring Cosmology in 2003.

# 1 Introduction: The “Vacuum Selection” Problem

From the beginning, the seemingly vast array of possible ground states has made string theory both attractive and problematic. Ground states with more than four supersymmetries have the virtue that they are theoretically tractable, but they are also totally unrealistic. It has long been clear that no potential for the moduli exists, and the duality revolution spoiled any remaining hope that some sort of non-perturbative inconsistency might permit us to discard these states. It also strongly suggested that this proliferation of possible ground states is an inherent feature of any sort of quantum general relativity. Apart from anthropic arguments (to be discussed below), we have no inkling why nature doesn’t select one of these states. With four or less supersymmetries there is a vast proliferation of candidate ground states, revealed in various approximations. Some of these have features which resemble those of the real world. Unlike the case of more supersymmetries, there are potentials for the moduli, tadpoles (either at the perturbative or non-perturbative level), and some possibility of non-perturbative anomalies. Faced with this plethora of states, I, for a long time, comforted myself that not a single example of a (meta)stable ground state of this sort had been exhibited in a controlled approximation, and so perhaps there might be some unique or at least limited set of sensible states.

One of the most exciting – and troubling – developments in string theory in the last few years has been the suggestion that there is a vast array of stable or highly metastable states of string theory with four or less supersymmetries. Crucial to the emerging picture is the role of compactification with fluxes.[1, 2, 3, 4, 5, 6] The most persuasive elaboration of this possibility to date is due to Kachru, Kallosh, Linde and Trivedi (KKLT),[7] who argue for the existence of a *discretuum* or *landscape*,[8] both supersymmetric with  $N = 1$  supersymmetry, as well as non-supersymmetric, with supersymmetry softly broken. The existence of a landscape, if established, raises questions about the very nature of scientific explanation. Most importantly, this assertion places the anthropic principle at center stage. There has been strong reaction to this fact, ranging from near celebration by advocates of the anthropic principle to a great deal of handwringing and even denunciation from those who find the anthropic principle objectionable.

In this talk, I would like to give an overview of some of the issues raised by the possible existence of a landscape. I will explain why, even before we accept the landscape, some element of anthropic explanation is probably inevitable in quantum general relativity. Understanding the number of supersymmetries and the dimension of space-time may well require invoking some *extremely* weak anthropic considerations (what we might call the Minimalist Anthropic

Principle, or MAP).

But the landscape requires a much broader application of the anthropic principle. I will stress in this talk is that the questions of the applicability and validity, of the anthropic principle are *scientific* ones. As to applicability, I will discuss what I believe has been reliably established by KKLT, and what has not (in this context I will present a few, admittedly very tenuous reasons, to hope that some sort of unique or nearly unique set of predictions emerge from string theory). I will mention various proposals for anthropic explanations of the cosmological constant, and show that, apart from the landscape, our experience with string theory renders the others (almost) implausible.

Then I will turn to the question of whether the anthropic principle is predictive or falsifiable. Michael Douglas[9] has put forward, most clearly and persuasively, the question of anthropic prediction in this context, though he prefers not to use this language. In particular, he stresses that the important question is determining the probability distributions for various physical quantities in the flux discretuum. One could imagine that, if these distributions were well understood, the anthropic principal could become predictive – and falsifiable. The typical vacuum consistent with anthropic constraints might not look at all like the Standard Model, or it might make a prediction, say of supersymmetry or some large dimension. Indeed, while these distributions are not yet sufficiently well known to make definite statements, I will argue that it is almost inevitable that this framework will predict low energy supersymmetry. But I will also explain why it is also likely to make a number of incorrect predictions. More precisely, if the flux discretuum is to describe nature, there are many questions whose explanations cannot be anthropic, but must emerge as a result of physical principles. These principles are not apparent in the landscape as envisioned by KKLT. This may be a sign that the discretuum is the *wrong* direction to understand fundamental issues in physics. Alternatively, it may mean that the business of particle physicists will be extracting these principles. In either case, we should neither *despair nor give up!*

## 2 How Many Supersymmetries?

Why don't we live in a universe with more than four supersymmetries? As I indicated above, there is almost certainly nothing wrong with these vacua. One could imagine that these are somehow disjoint theories from that which describes what we observe. This viewpoint has been put forward by Banks.[10] It has long seemed to me that some very mild anthropic considerations

might rule these out (no conventional stars? no inflation? no structure?) I don't think that most of us would find this Minimalist Anthropic Principle particularly disturbing. It would not render the theory unpredictable or unfalsifiable.

What about theories with less supersymmetry? In some sense, theories with  $N = 1$  supersymmetry are not, at first sight, obviously different than those with  $N = 0$  supersymmetry. After all, generically one expects potentials on the moduli spaces of both albeit perturbatively in one case and non-perturbatively in the other. In my view, there is some tentative evidence that there is a real distinction. First, however, since we are speaking, at best, of approximate supersymmetry, we need some definitions. I will refer to  $N = 0$  theories as theories for which there is no limit of the moduli space with only a finite number of supersymmetries. Examples include (compactifications of) the  $O(16) \times O(16)$  heterotic theory, the non-supersymmetric heterotic M-theories studied by Fabinger and Horava, and others.  $N = 1$  theories are those with only four supersymmetries in *some* limit of the moduli space. Familiar examples include the heterotic and Type I theories on Calabi-Yau spaces, orientifolds of Type II theories on Calabi-Yau, and many more.

The  $N = 0$  theories have a number of properties, which suggest that they might be qualitatively different from the supersymmetric ones. Conceivably many (most?) of them suffer from various diseases. One potential problem is the appearance of tachyons appear in the moduli space, but it is not clear that this signals any kind of consistency. Fabinger and Horava[11] have argued that  $N = 0$  theories may suffer, generically, from other instabilities, particularly Witten's "decay to nothing".[12]. With Fox and Gorbatov,[13] I have been following up this latter issue. We have sharpened, but not resolved, the question of the extent to which bubbles of nothing are generic to these spaces. There are, we believe, good reasons to think these instabilities *are* generic. We have also understood how these instabilities arise even in the presence of a potential on the moduli space, in  $N = 0$  theories (but not in  $N = 1$  theories). But while the prospect of decay to nothing is frightening, it is not clear whether this means that these states don't make sense as quantum theories. Still, it seems possible that with some work we can show that large classes of  $N = 0$  theories don't make sense.

The discretuum suggests another approach to this question. As we will see, it is plausible (*but certainly not established*) that vacua with low energy supersymmetry, consistent with modest anthropic constraints, are by far the most numerous.

Before exploring anthropic arguments, it is worth noting that in controlled approximations, we don't presently know how to make sense of most (any?) string solutions with four or less

supersymmetries. Generally, because there are potentials on the moduli space, they are cosmological with singularities in their past or future, which we don't know how to treat.[14] Perhaps this is cause for optimism. After all, for space-like singularities, we know that string theory sometimes provides a resolution, and we know (in weakly coupled strings and sometimes elsewhere) the criterion (modular invariance). Perhaps there is an analogous condition for time-like singularities. If we were lucky, perhaps this condition would yield only a small set of consistent theories.

### 3 The Dreaded Anthropic Principle

Linde was probably the first to realize that inflation leads to a framework in which one might sensibly implement the anthropic principle.[15] Perhaps in a very vast universe, the fundamental parameters take different values in different regions. The most promising application of this idea has long been to the problem of the cosmological constant, for which it is fair to say that we currently have no equally successful candidate solution.[16]

The response to this suggestion has been enthusiasm in some quarters and revulsion in others. I have been more agnostic, and I strongly believe that the question itself is a scientific one. If string theory provides a means to implement the anthropic principle, then we *have no choice but to consider it seriously*. Rather than wasting time arguing about philosophical issues, I think the smart money will be on trying to figure out whether one can make predictions or falsify the theory. Some ideas for how predictions might emerge will be discussed below. If string theory does not provide a setting for the anthropic principle, while we can't, perhaps, "disprove" it, I think we can justifiably, *and smugly*, ignore it.

There are, to my knowledge, two principle scenarios for implementing the anthropic principle:

1. Extremely light scalars:[17, 18, 19] Here, if one is to solve the cosmological constant problem, one requires a scalar with a mass smaller than the present Hubble constant, but which varies over such a large region of field space that it can cancel an energy density at least of order  $\text{TeV}^4$ .
2. A discretuum or landscape [20, 1, 2, 7] (as for the references, the first provided a simple model based on an "irrational axion", but no example of this type has been exhibited in string theory; the second and third used fluxes in a manner not too different than that

currently of interest; the last is the most fully developed of these ideas).

Each of these scenarios is quite radical, and their plausibility cannot be assessed without a theory which is fundamental (in the sense of including gravity and other interactions, and finite) like string theory.

### 3.1 Extremely Light Scalars

In string theory, it appears unlikely that there are scalars with the requisite properties to solve the cosmological constant problem.<sup>1</sup> Ordinary scalars in string theory have masses generally have masses consistent with dimensional analysis, e.g. set by the scale of supersymmetry breaking. String theory also has periodic scalars, for which shift symmetries can suppress masses. So these might be candidates, but one needs decay constants far greater (exponentially greater) than the Planck mass. Searches in string/M theory have not yielded any candidates.[24] (Such fields would also be of interest as candidate inflatons.[22])

While this cannot yet be considered a theorem, it seems unlikely that this sort of implementation of the anthropic principle is realized in string/M theory. What is perhaps most interesting is that it might be possible, with a finite amount of effort, to rule out this implementation completely.

### 3.2 Discretuum or Landscape

There have been various proposals for a discretuum. That of [20] does not seem to be realized in string theory. That of [1], while interesting, made assumptions about the stabilization of moduli for which there was no support. The proposal of [7] is the most promising to date, including, as it does, a detailed picture of the stabilization of moduli. This proposal is the subject of the next section.

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<sup>1</sup>Dimopoulos and Thomas[21] have recently suggested a possibility which could conceivably be realized in string theory: they have argued that a conformal field theory might yield a huge  $Z$  factor for some scalar field. This possibility is worthy of further exploration. This discussion itself is an example of how the anthropic principle is an issue whose validity and relevance can be decided by scientific means.

## 4 The Proposal of KKLT

KKLT have put forth a quite detailed proposal for how a landscape might emerge in string theory. There is not space here to fully review this set of ideas, but we should note, first, that they are based on effective field theory. Banks has argued cogently that one cannot use effective field theory to study multiple vacua in theories of gravity.[23] For example, in many circumstances there are no transitions between the different states, and an observer in one can not do experiments which will indicate the existence of others. So it is not clear that the multiplicity of states has any meaning. These arguments have been reviewed and elaborated in [25].

Setting aside these larger questions of principle, I want to focus here on questions of self-consistency with the effective action analysis. I will not be able to fully answer whether KKLT have actually demonstrated the existence of a discretuum. My tentative conclusion will be that there is a discretuum of states with  $N = 1$  supersymmetry, but that only a limited set of quantities can actually be computed in these states. Because of the latter problem, studies of supersymmetry breaking may be more problematic, but the existence of a supersymmetric discretuum is at least plausible. Some of these questions can probably be answered through further investigation.

Compactifications of string theory (IIB on a CY, X, or  $F$ -theory on a Calabi-Yau four-fold, for definiteness) permit many possible quantized fluxes,  $F_{IJK}, H_{IJK}$ . The number of possible three cycles ( $b_3$ ) can be of order 100's. These fluxes are not highly constrained. Tadpole cancellation gives one condition on many fluxes. Because there are so many possible choices of fluxes, there are potentially an exponentially large number of states.

KKLT, following earlier work[5, 3, 6] noted that the presence of flux tends to stabilize moduli. For example, [5] considered orientifolds of Type II theory on a Calabi-Yau space near a conifold point. If  $z$  is the modulus describing the distance from the point, then in the presence of flux on the collapsing three cycles one finds both stabilization and warping. There is a superpotential for  $z$  and the dilaton,  $\tau = \frac{i}{g} + a$ ,

$$W = (2\pi)^3 \alpha' (M\mathcal{G}(z) - K\tau z) \tag{1}$$

where  $M$  and  $K$  denote the flux quanta, and

$$\mathcal{G}(z) = \frac{z}{2\pi i} \ln(z) + \text{holomorphic}. \tag{2}$$

This effective action has a supersymmetric minimum where

$$D_z W = \frac{\partial W}{\partial z} + \frac{\partial K}{\partial z} W = 0 \quad (3)$$

This is solved by:

$$z \approx \exp\left(-\frac{2\pi K}{Mg_s}\right) \quad (4)$$

If the ratio  $N/M$  is large, then  $z$  is very small. The corresponding space can be shown to be highly warped. In addition,

$$W_o = \langle W \rangle \quad (5)$$

is exponentially small.

Including additional fluxes, it is possible to fix other complex structure moduli and also the dilaton,  $\tau$ .

$$W = (2\pi)^3 \alpha' [M\mathcal{G}(z) - \tau(Kz + K'f(z))] \quad (6)$$

$$D_\tau W = \frac{\partial W}{\partial \tau} + \frac{\partial K}{\partial \tau} W = 0$$

for

$$\bar{\tau} = \frac{M\mathcal{G}(0)}{K'f(0)} \quad W = 2(2\pi)^3 \alpha' M\mathcal{G}(0)$$

$z$  is still exponentially small, and the space is highly warped, but *now  $W_o$  is no longer exponentially small*. This is crucial to the KKLT picture. In the limit that  $R$  is very large, there is no potential for  $R$ ; the compactification radius is not fixed.

#### 4.1 Fixing the Remaining Moduli?

KKLT noted that in flux vacua,  $W_o$  is generically large (of order some typical flux integer), but argued that among the vast number of possible fluxes,  $W_o$  will sometimes be small, simply by chance. Other effects (e.g. gluino condensation) will generate a superpotential for  $\rho = R^4 + ib$ :

$$W = W_o + e^{-\rho/c} \quad (7)$$

This has a supersymmetric minimum, with

$$\rho \sim -c \ln(W_o) \quad (8)$$



Consistency of the analysis requires that  $\rho$  be large, but this will be the case only in an exponentially small fraction of states.

If there is a systematic approximation, it consists of integrating out the string modes followed by the KK modes, the complex structure and dilaton, and finally the radial mode. Consistency requires a hierarchy of masses:

$$M_{string}^2 \gg M_{kk}^2 = 1/R^2 \gg M_{\tau^2, z^2} \gg m_\rho^2. \quad (9)$$

Before making detailed calculations, these conditions seem to hold at large radius. The masses of the  $\tau$  and  $z$  fields are suppressed by  $\rho$  relative to the Kaluza-Klein modes, and by  $\rho^{3/2}$  relative to the string scale. But in the presence of large fluxes or large  $b_3$ , there are a number of sources of enhancement, which can be inferred from the expression for the superpotential:

1. Factors of fluxes,  $(N, M)^2$
2. Factors of  $\tau$ ,  $\tau^2$
3. Factors due to the large size of the mass matrix,  $b_3$ . In the absence of any detailed understanding of the mass matrix, we might worry that a large, random matrix has eigenvalues which grow with the size of the matrix.

This list suggest that one might expect that

$$\frac{m_{z, \tau}^2}{M_{string}^2} = \frac{b_3 \tau^2 N^2}{\rho^{3/2}}. \quad (10)$$

If we require, say  $\tau = 5$ , and suppose that a typical  $N$  is of order 3, this requires that  $\rho$ , be quite large, and therefore that  $W_o$  is *extremely* small. Indeed, if we take for the number of states that suggested by KKLT and by Douglas,  $e^{b_3 \ln(\frac{X}{24}/2)}$ , there might well not be enough states that one could imagine doing a self-consistent computation in *any* of them.

But this may not call the KKLT discretuum into question.<sup>2</sup> Imagine studying the theory at extremely large  $\rho$ . Here, one can compute  $W_o$  reliably. One can also compute the leading  $\rho$ -dependent terms in the superpotential. Because of non-renormalization theorems, this form of the superpotential will remain valid until the point where higher order exponentials become important. This requires only that  $e^\rho$  be small, which would seem to be a much weaker requirement than equation [?].

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<sup>2</sup>I thank the participants at the KITP workshop on string cosmology for discussions of these issues, and especially Joe Polchinski.

Supersymmetry breaking, from this point of view, could be more problematic. One will not have the same level of control of the Kahler potential, for example.

It is worth stressing what serves as the small parameter which justifies analysis in the landscape. It is not large flux numbers or large  $b_3$ , per se, but the fact that in the vast discretuum of states, there is a small fraction – but large number – of states with small  $W_o$ .

## 5 Supersymmetry and Supersymmetry Breaking

For now, let's accept that a discretuum exists, and that the universe samples all of these states in its cosmic history. KKLT argued that anti D3-branes, located well down the throat can give exponentially small effects in a warped geometry. An alternative possibility, which is perhaps somewhat easier to think about, is to note that in some fraction of this vast array of states, the low energy dynamics presumably breaks supersymmetry. (By assumption, the discretuum contains states with complicated gauge groups and chiral fermions.) Then

$$V = \exp(-8\pi^2/b_o g^2) \tag{11}$$

If  $g^{-2}$  is distributed more or less uniformly,  $V$  will be distributed roughly uniformly on a log scale. Correspondingly, there will be a substantial number of states where the cosmological constant,

$$V = [\exp(-8\pi^2/b_o g^2) - 3|W_o|^2] \tag{12}$$

is small compared to  $|W_o|^2$ .

## 6 Anthropics

So we have a picture in which there are many, many states. Among these states, quantities relevant to low energy physics vary:

- Low energy gauge groups
- The matter content
- The values of the parameters of the low energy lagrangian.

If the universe samples all of these states, there will only be observers in a subset with suitable properties.

## 6.1 The Cosmological Constant

The cosmological constant provides the most compelling application of the anthropic principle.[16] Holding all other fundamental and cosmological parameters fixed, one finds that suitable structure forms only if  $\Lambda$  is less than or of order 10 times its observed value<sup>3</sup>.

## 6.2 Does the Anthropic Landscape Predict Low Energy Supersymmetry

We cannot prove at present that the landscape predicts low energy supersymmetry, but it seems likely that it would. As Douglas has explained (see also [25]), for small  $W_o$ , the distribution of  $W_o$  is likely to be uniform. Suppose, also, that the origin of supersymmetry breaking is dynamical, as described above, and that  $\frac{8\pi^2}{g^2}$  roughly uniformly distributed. Then, e.g., if  $W_o = 10^{-28}$  (susy breaking  $\sim 10^4$  GeV), in about  $10^{-3}$  of states,

$$V_o = e^{-\frac{8\pi^2}{bg^2}} - 3|W_o|^2 < |W_o|^2.$$

In this subset of states one has the possibility of obtaining a small cosmological constant.

Suppose that the anthropic argument for  $\Lambda$  is correct. We can compare the number of states with sufficiently small  $\Lambda$  with and without supersymmetry. Of course, since we have not done a reliable counting, we are describing here only a program which might lead to such a prediction, and its hypothetical results.

Without supersymmetry, we might expect simply:

$$P(\Lambda) \approx \frac{\Lambda}{M_p^4}.$$

(here  $P$  is the probability of cosmological constant less than  $\Lambda$ ).

With supersymmetry, we start with the probability of small  $W_o$ :

$$P(W_o) \approx \frac{W_o}{M_p^3}.$$

Now small  $\Lambda$  will favor small supersymmetry breaking. This is the usual argument about the connection of the cosmological constant and the scale of supersymmetry breaking, and it remains valid in this framework. This means that we will require more anthropic input. In particular, we might imagine that the ratio:  $M_w/M_p$  is fixed (note that we would also require something like this for non-supersymmetric theories, presumably, to account for the hierarchy). So we might estimate the fraction of suitable states along these lines:

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<sup>3</sup>Allowing other quantities to vary permits a far broader range of  $\Lambda$ . See, e.g., [26]

1.  $10^{-10}$  have suitable susy breaking (i.e. low energy gauge groups with suitable properties)
2.  $10^{-2}$  have susy breaking comparable to  $W_o$
3.  $10^{-13}$  have suitable  $W_o$ .
4.  $10^{-60}$  of these have small  $\Lambda$ .

So we guess that for supersymmetric states, we pay a factor of  $10^{-85}$  to realize this set of anthropic constraints, vs.  $10^{-120} \times 10^{-32}$  for non-susy states. So SUSY wins unless there are an overwhelmingly large number of non-susy states relative to supersymmetric ones. Note that this picture favors susy breaking at the lowest possible scale (gauge mediation?)

So one sees here how the anthropic principle, coupled with knowledge about the distribution of states, might lead to a real prediction. But before getting too excited, there are other issues to face in the flux discretuum.

### 6.3 Anthropic Pitfalls

A program of implementing the anthropic principle within the landscape faces several hurdles, and at least at first sight, seems likely to fail. Within the landscape, as we currently imagine it, there are numerous states with different gauge groups, particle content, and couplings. These features must either be fixed anthropically, or are otherwise random. But there are many features of the Standard Model which seem neither anthropically constrained *nor random*. [27]

In thinking about this sort of anthropic selection, it is useful to organize the problem by considering physics first at very large distance scales, and then at progressively shorter scales, using the language of effective actions and the renormalization group.

At the very largest distances, we face the problem of the cosmological constant, which we have already discussed. At shorter distances, we face the question of the existence of an unbroken  $U(1)$  symmetry. This is plausibly anthropic. The question of whether the strong group is  $SU(3)$  or something else might be anthropic, but this is more difficult to decide. E.g. for groups other than  $SU(3)$ , by varying  $m_u$  and  $m_d$  we can probably reproduce many features of nuclear physics. Conceivably deuterium is essential for stellar nucleosynthesis, and this might single out  $SU(3)$ . The ratio  $m_e/\Lambda_{qcd}$ , another important parameter of the low energy lagrangian, might be fixed, for example, by molecular physics and/or by astrophysics. The relative size of  $m_u$  and  $m_d$  might also be determined by the details of nuclear physics; at the

grossest level, the fact that  $m_d > m_u$  is necessary for proton stability (as opposed to neutron stability).

While plausibly constrained by anthropic arguments, making persuasive arguments for these quantities will be challenging, at the very least. But at higher energies, we encounter couplings whose prediction is more problematic:  $m_s, m_c, m_b, V_{km}$ . It is hard to see how these could be anthropic (if there were obvious anthropic arguments, one might have predicted the values of these quantities prior to their discovery). One of the most puzzling is  $\theta_{qcd}$ . It is not at all clear what sort of anthropic argument might require  $\theta_{qcd} \ll 1$ .

In the landscape, it would appear that all of these quantities are simply random numbers.  $\theta_{qcd}$ , for example, is presumably not small in a typical vacuum. The fluxes, generically, break CP and contribute to  $\theta_{qcd}$ . Moreover, the assumption is that all of the moduli are fixed would seem to preclude axions. E.g. cross terms in the potential for  $\rho$  involving  $W_o$  will give a large potential to the pseudoscalar component.

At still high energies, one encounters further questions. The weak gauge group may be hard to understand anthropically. Dark matter, cosmological parameters (the size of inflationary fluctuations, the number of  $e$ -foldings, and the like) will pose deeper challenges.

In the flux discretuum, the parameters of low energy physics seem to be random numbers. If this is really true, the landscape is not a correct description of physics. Alternatively, there are some set of principles in the landscape which explain those laws of nature which do not seem to be anthropically constrained. Within the flux discretuum, it is not obvious what these might be. As another example, anthropically, the proton lifetime is probably not required to be much larger than  $10^{16}$  years. So one might hope to understand the length of the proton lifetime from symmetries. But most states of the flux discretuum don't have symmetries.<sup>4</sup> For  $\theta_{qcd}$ , we might want to find a reason why some modulus is not fixed at high energies. One could imagine that this is cosmological.

## 7 Conclusions

Whether one likes it or not, it is quite possible that quantum theories of gravity predict a landscape. It is plausible that the flux vacua explored by KKLT exist, but it is by no means certain.

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<sup>4</sup>For example, in the case of the  $T_6/Z_2$  orbifold, one has a  $Z_2^5 \times S_6$  symmetry at some points in the moduli space. But half of the fluxes must vanish to preserve even one  $Z_2$ . In more realistic models, this is likely to correspond to a drastic reduction of the number of states in the discretuum.

Perhaps the strongest reason for doubt is Banks' general critique of effective action methods in gravity theories, but I have mentioned some concerns within the conventional framework of effective actions. I have also mentioned some curious issues of scales, within the framework of effective field theories. One interesting feature of the proposed discretuum which we have noted is that the small parameter is essentially a random variable.

If there is a discretuum, it seems quite likely that we will be able to falsify this whole picture. Typical states, even subject to anthropic constraints, will disagree violently with observation. To avoid this conclusions, we would need to show that in some subset of states – which are picked out by other considerations – there is some rational explanation of the many features of the Standard Model which don't seem susceptible to anthropic explanation. We have seen, for example, how low energy supersymmetry could conceivably emerge from the requirement of small cosmological constant and suitable electroweak symmetry breaking. Perhaps some considerations might lead to approximate flavor symmetries, small  $\theta$ , and the like. On a pessimistic note, we have argued that symmetries are unlikely to play this role.

Mention of the anthropic principle brings out strong reactions from most physicists, who ask what can be the role of science in such a situation. But the lesson of the KKLT proposal is not so pessimistic. First, the existence of a landscape within string theory is a question we should be able to decide. If we decide that there is such a discretuum, we will probably be forced to contemplate the anthropic principle; if not, we can dismiss it. But even if we do adopt the anthropic principle, it will at best explain only a few quantities: either we will falsify string theory, or we will uncover principles which explain most of the features of the Standard Model. We will likely make additional predictions for accelerators and cosmology as well. So surrender to the anthropic principle will not be necessary or possible; we won't have to give up.

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